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GROUND WATER PROSPECTING

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Ground Water Prospecting

by
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1. According to the Oxford Dictionary the meaning of the word "Prospecting" is "the exploration of a region" and the use of the word conjures up a sense of adventure, independence of thought and a degree of uncertainty.

2. Adventure is fulfilled by each assignment differing in detail from previous ones.

3. Independence of thought is essential as the ground water problem of any area under review is unique. Whilst it is possible for ground water in certain regions to be similar, detailed variations of the many variables affecting it's incidence necessitate a complete freedom from stylisation of approach.

4. The degree of uncertainty is always present as existance of useful ground water and the quality thereof cannot in man's present understanding of the problem be forecast beforehand with precision.

5. UN. Publication 60 II B3 of 1960 Annex III Para 265 describes ground water "as an element of the hydrological cycle. The study of the ground water phase involves features that are different from studies of other parts of this cycle."

6. Para. 266 continues "The investigation of ground water resources requires information on their occurrence movement, storage, recharge, discharge, quality and quantity."

7. To enable ground water prospecting to succeed adequate finance is necessary. The main skills required are engineering and geology - all others support these two.

8. Successful prospecting is dependent on first class teamwork uniting the specialist skills required in the search for underground water. The team will have to cover the following branches:-

   (a) Engineering.
   (b) Geology.
   (c) Aerial Photography and Interpretation.
   (d) Survey and Mapping.
   (e) Geophysics.
   (f) Agriculture and Soil Agronomy.
   (g) Hydrology.
   (h) Economics of Development.

   The requirements of each branch are closely knit with those of the others and problems and results affecting one will have repercussions on most others.

9. Ground water exists in a vast number of localities but only a comparatively small amount is of a quality and quantity useful to the needs of man.

It is emphasized that :-

(a) All underground water originates as rain.
(b) Useful water cannot be found where it does not exist.
(c) Water reserves must be found and tapped before it is possible to ascertain the quality and quantity of water that can be safely withdrawn without depleting these reserves.

10. Ground water has the following advantages :-

(a) It is not subject to evaporation in its underground reservoirs.

(b) It is not generally subject to high bacterial pollution although in certain circumstances development on a catchment area contributing to underground water has got to be very carefully controlled.

(c) The constitution of underground water is fairly constant provided that over-abstraction is not practised.

(d) Draw-off from underground water resources can be controlled through control of pumping rate and therefore in periods of low demand it is not necessary to abstract from the underground water reservoirs.

(e) Recharge of underground reservoirs can be practised although this branch of water conservation is still in its infancy and considerably more experimental work is required in this field before related problems are fully understood.

11. Disadvantages of ground water are :-

(a) Generally reservoirs require pumping for abstraction and therefore production is comparatively costly.

(b) In many cases fairly long transmission lines are required to convey water from the underground reservoir to the source of use.

(c) In certain areas chemical pollution of water can be rapid if over-pumping takes place.

(d) In a well developed scheme abstraction rates should be carefully balanced against replenishment and this may set a limit on the amount of water which can be utilised.

12. In spite of many claims, there is no short cut way to success in ground water prospecting and all work must be methodically undertaken in the following order :-

Phase I	Initial Reconnaissance.
Phase II	Survey.
Phase III	Assessment of Drilling Requirements.
Phase IV	Fieldwork.
Phase V	Development.
Phase VI	Control of Abstraction.

Phase I - Initial Reconnaissance.

13. It is essential when considering a programme of ground water prospecting for administrators initiating the scheme to invite a report from an expert who will give sound impartial advice as to the feasibility of the project as the result of an initial reconnaissance.

14. This enables the expert to study local needs, to get a feel of the country, to assess the problems to be met and to formulate a phased plan covering the various stages of ground water prospecting. Provided expenses are covered the Report produced as a result of such a visit costs little and forms the basis for forward budgetting. It also shows how a phased programme of fieldwork and development should be put in hand.

15. This phase would include amassing all topographical and regional geological information available about the area and would be further extended by questioning of local people and by reviewing any history of search or failure of water which might have occurred in the past. Co-ordination of historical information concerning previous use of water is of great importance as although in the past it may not have been possible for scientific analysis to have been made, the economics of the search for water may then have been totally different from today.

16. In the days of large empires and huge labour forces (generally acquired as a spoil of war) it was possible to seek water by non-scientific means because the need to gain it was a dire necessity for survival. Further, in ancient times vast areas are known to have been irrigated and to have been fertile where now little or no cultivation exists.

17. The destruction of empires by political or natural forces has often allowed these ancient water sources to fall into disuse and recent discoveries have testified to the great engineering ability of ancient civilisations to make the most advanced use of the water available in their area. Such massive works of irrigation and transmission of water were possible only by means of the ready availability of labour.

18. Very often the reasons for siting ancient wells in specific locations has been lost in the mists of antiquity and the Author's practice is to investigate all possible sources, historical or legendary of the search for water. Certain wells in Arabia have been known to produce water before the days of the Prophet.

19. Today alternative means are available in the form of international finance, technical aid and scientific knowledge.

20. The expert engaged for the initial reconnaissance will formulate plans for the carrying out of the remaining phases of the work and should also give indications of chronological timing and financial control. It should be noted that the following phases may be put in hand in sequence or may proceed side by side dependent upon the precise nature of the problem in hand.

Phase II - Survey.

21. This should include in greater detail than was possible in the Initial Reconnaissance, a close study of the History, Topography, Geology and Meteorology of the area under review.

22. Should sufficient survey information not be available air photography can be used to establish this both quickly and cheaply. It is not always essential that ground control be set up for this purpose and very often uncontrolled mosaics are sufficient to commence initial investigations with properly controlled mapping following later.

23. Skilful interpretation of air photography can establish :-

(a) The presence of ancient irrigation systems and cultivated areas now disused.

(b) The watersheds and drainage basins of the area under review.

(c) Surface geological features.

(d) Present day types of vegetation cover.

In addition it provides a basis from which the prospecting can be controlled.

24. Sub-surface geological records should be studied and assessed if any exist. Preliminary work can be carried out to investigate major items of loss of water by soakage, run-off to sea, evaporation, underground water wastage from the area, intrusion of brackish water either from inland or sea sources. Also an indication can be given of the rate of replenishment of underground reserves from the depositions on or adjacent to the area.

25. In areas where the watertable is shallow the hand-digging of wells should be encouraged pending the arrival of suitable drilling gear if skilled well diggers are available.

26. During this survey period too, it should be possible to arrive at an overall assessment of the different types of water which are required in the country concerned. These would comprise :-

(a) Potable and Sanitary Water.
(b) Agricultural and Horticultural Water.
(c) Industrial Water.
(d) Brackish Water.
(e) Salt Water.

Potable Water Standards.

27. Impurities in water are measured by the total dissolved solids content and in more advanced civilisations this may be held to a figure of 35 to 70 parts per million. In arid zones large

numbers of people exist quite comfortably on semi-brackish water of the order of 3500 parts per million total dissolved solids. Where practicable a limit should be set at not greater than 1500 parts per million.

28. There are certain limitations to the individual components of chemical origin and great care has to be exercised in ensuring that none of the individual components can cause serious difficulty to the populations concerned. Examples of this are excess salt or sulphates. Excess nitrates may give cause to the production of "blue babies". In other words it is essential that a properly balanced water is brought into use.

Agricultural Standards.

29. In the same way there are specific requirements for chloride and other chemical make-up in connection with water for agriculture, stock raising and other special horticultural purposes.

Industrial Water Standards.

30. Should underground water be required for advanced industrial purposes, it may be necessary to de-mineralise it in order to produce the very high purities which are necessary in certain advanced applications such as for example use in super high pressure boilers. On the other hand, brackish water may be suitable for some industrial uses.

Salt Water Standards.

31. Occasionally connate water is mined for processing by evaporation to produce rock salt or other minerals. In this case standards may allow the use of ground water having a total dissolved solids content greater than sea water.

Phase III - Assessment of Drilling Requirements.

32. Upon analysis of topographical and surface geological information, it is possible to assess drilling requirements necessary to probe into the sub-surface geology and the underground reservoirs.

33. Dependent upon the nature of the terrain, water may be found at shallow, intermediate or deep horizons.

These are defined as :-

Shallow	-	down to 500 feet.
Intermediate	-	500 feet to 1000 feet.
Deep	-	over 1000 feet.

However, it is not usual for water of usuable standards to be gained from horizons more than 3000 feet deep.

34. Water may be found in the drift geology or in the solid geology or both and both potential sources must be investigated.

35. Accessibility of drilling sites and transportation of rigs have to be considered.

36. The following styles of equipment are available :-

(a) Percussion cable rigs.
(b) Rotary rigs using conventional mud circulation.
(c) Rotary rigs using air blast ejection.
(d) Air turbine rigs.

The last two types are new and subject to proving and development.

37. Unless other geological studies are available in the area some coring will be essential to establish geological sections and therefore a proportion of rotary rigs will usually be required.

38. There is naturally some overlapping of the depths which can be reached by various styles of equipment but for water prospecting the following arrangements have proved satisfactory.

39. Percussion cable rigs are simple, robust and suitable for operation down to depth of about 800 feet although heavier types can reach greater depths. It is possible to train local

personnel to operate these rigs satisfactorily provided that a competent drilling superintendent is available for general training and guidance.

40. The success of any drilling operation depends entirely upon first-class maintenance of rigs and tools and it is essential that very adequate servicing and replacement facilities are available because of the very heavy wear on equipment during operation. The use of unsharpened or improperly kept tools is uneconomic and the continuous replacement of drilling wires, engine parts etc., is essential to safeguard men's lives and to enable the project to proceed smoothly.

41. For the intermediate range of about 500 feet to 1000 feet, and in rock formations, it is generally necessary to utilise the more complicated light rotary drilling rig with rock cutting bits. Extremely heavy wear can be encountered in these conditions and essential maintenance and servicing requires more comprehensive workshop facilities than is the case for percussion rigs.

42. In certain formations it may be necessary to change to diamond or carbide tipped drilling bits. The use of these is expensive and is usually confined to essential sections only.

43. Over a depth of 1000 feet it is usually essential to utilise heavy rotary drilling rigs and these may be of varying power and size dependent on the formations through which one has to drill. The ultimate being the type of rig utilised for oil well drilling which may start off with a 21 inch hole at the surface for spudding in.

44. In the air blast ejection rotary rig drilling mud is not circulated to the bit but a blast of air is directed at high pressure through the centre of the drill stem and this is sufficiently powerful to eject the fine drill refuse from the bottom of the hole up the side of the hole and to the surface. This rig is useful for operations on an exploratory basis in dry formations down to the water table in desert countries. However, it has not yet been used sufficiently to be able to ascertain whether it has any benefit over the normal mud circulation rig for the drilling of production holes.

45. Within recent years the Russians have developed an air turbine drilling rig in which the drill stem is held stationary and does not rotate and the drilling bit is rotated by an air turbine suspended at the end of the drill stem. This turbine is driven by high pressure air fed down the centre of the drill stem and the bit is rotated at high speed. Use of this type of rig has chiefly been for the search of oil but it could have advantages in the search for water.

46. At the top end of the scale for shallow excavation work sight should not be lost of the use of small tube wells which can be inserted in some grounds by hand or by means of auger boring or percussion boring down to depth of about 50 feet to 100 feet.

47. The style of formation to be encountered will legislate whether one has to use casing throughout or in part of the hole and normal drilling practice has to be followed in this problem as it is extremely expensive in time and money to get a "cave in" with the possible consequence of having to abandon hole and the drill stem therein.

48. A recent development for casing shallow wells is made of aluminium which allows break down into packs suitable for animal transport, but which can be assembled on site to form a hexagonal section.

49. Excellent exploration work has been done in the Middle East with cheap forms of casing which have been transported as flat strip and rolled on site and welded and inserted into the drill hole with consequent economy.

50. On the majority of surveys some coring will be necessary. For this it is more economic to use smaller types of diamond coring drills of NX and BX sizes rather than to utilise full-scale production drills. The diamond coring drills can reach to considerable depth and are satisfactory for producing a comparatively cheap core up to 2½ inches diameter. Generally speaking smaller cores than this are not suitable for detailed examination in the laboratory.

Phase IV - Fieldwork.

51. It is the Author's firm belief that only by drilling sampling and applying pumping tests can the reasonable assessment of reserves of water be achieved. There is no short cut method although some clients are taken in by claims as to the efficacy of easy methods.

52. Clients accepting these assurances have attempted to do without a proper hydrogeological investigation and have gone straight into production drilling only to find that after a large expenditure of money the water produced is unsuitable.

53. It is advisable to go to tender for the services of drilling specialists and it is emphasised that the international field of competent good drilling contractors with skill in the search of water is limited. Specialist knowledge accumulated of specific regions is a valuable adjunct at this stage. Open tender therefore is not to be advised and selected or nominated contractors only should be asked to bid.

54. Drilling should be to a prescribed programme which will support and prove geological theories.

55. Rainfall recording stations should be set up and arrangements made for the security thereof.

56. At this stage arrangements must be made to set up a careful control to rapidly analyse and evaluate all data gained in the field. This is essential to ensure the intimate and proper co-ordination of all skills.

57. Control of the survey can be done by plotting parameters for several characteristics. These may be :-

(a) Total dissolved solids.
(b) pH.
(c) Chloride Content.
(d) Sulphate Content.
(e) Any other harmful Content.
(f) Electric Conductivity.

58. Laboratory methods of determination of the complete chemical contents of water are lengthy and time consuming. They are not rapid enough for the efficient daily control of the survey.

59. The Author in common with other workers in this field therefore normally uses Electric Conductivity as a control; plotting what he has termed "isocons". These are lines joining points of equal electric conductivity and can be used to compare results from boreholes tapping into the same water source.

60. The apparatus used to measure electric conductivity consists of a small hand driven electric generator which discharges a current through a column of water between two electrodes spaced to compensate for the temperature of the water. A slipping clutch ensures that the electric discharge to the samples is at a constant potential and the conductivity of the sample is measured by a dead beat galvanometer.

61. Results can be obtained in a matter of minutes and provided the instrument is kept clean and free from contaminating salts, the results are consistent and reliable. The instrument is robustly made to endure prospecting conditions.

62. Team work is essential in the production of field work amongst the professions and technical skills which are necessary to mount a survey. The direction of this team should be by Engineers closely supported by Geologists.

63. The team will require to be organised according to the scale of operations and in a small survey it is probable that several functions can be performed by individuals doubling in the different professions backed up by specialist advice at base. On the other hand, a large-scale survey may mean the setting out of a very considerable field force to work in many areas at once.

64. To assist them in their work they should be in possession of as much topographical information as possible together with the basic geological information of the area and should have available mosaics from the aerial photography for the regions which they have to survey.

65. Whilst it is desirable to go in for full-scale triangulation this is not essential and very adequate work can be done by the utilisation of uncontrolled mosaics together with plane table equipment for local surveying and by using the aneroid barometer for elevation survey. The aneroid has certain limitations but it is usually possible to work to limits within + or - 3 feet and for many purposes it is adequate, certainly in the initial stages of the survey. The chief advantage is speed.

66. Accuracy should be introduced at some stage of the proceedings when a full-scale levelling survey or grid over the region should be undertaken to establish precise relationship between topographical and geological features and underground water tables.

67. It is also essential that the field staff be equipped with a reasonable laboratory to carry out initial testing of samples and that they be backed up by first-class base facilities. In these days of rapid air transport it is usually possible to get samples back to a fully established laboratory within a short time of sampling taking place at site.

68. Detailed study of air photography should enable the field party to establish water sheds, valleys, certain surface geological indications such as porous or impervious surface formations, anticlines, synclines, outcrops, faults, fissures and sink holes. In addition it may be possible to interpret stream effects, washes and run-off into the sea. Occasionally it is possible to determine the effect of wind erosion.

69. From this preliminary work on the air photography it is essential to plan the geological programme and field work and to ensure that this is in a methodical manner.

70. The geological survey will comprise three aspects :-

(a) The determination of the drift geology, if existent.
(b) The determination of the surface solid geology.
(c) The determination by drilling of the sub-surface geology.

71. Effects of glaciation, filling of depressions by washes, grouping of depressions and/or valleys by surface flow, sheet flooding, vegetation, fertile or infertile silting and mud trapping will be investigated as all of these aspects will have a bearing upon the problems. Regional developments such as the intrusion or emergence from the sea, the fall of the water table and the rise of land should also be studied. Water may occur in the drift geology or in the solid geology and both potential sources should be investigated.

72. The science of geophysics is a useful sound adjunct to cutting down drilling time and therefore expense. Four geophysical methods exist :-

(a) Seismic.
(b) Magnetic.
(c) Gravitational.
(d) Electrical.

Of these the electric method is the most useful in the search for ground water by the application of resistivity methods.

73. The detailed co-ordination of resistivity with geological finds has to be worked out as a result of field work for each area but once the inter-relationship is established a reasonable degree of certainty can be placed on geophysical predictions.

74. For each water source it is possible to establish fairly quickly a laboratory relationship between total dissolved solids and electric conductivity. Provided the source or type of water does not change this relationship can be used in the field and water sampling can be done by assessing the electric conductivity.

75. As results are obtained from boreholes various physical data is tabulated, such as :-

(a) Strike Water Level.
(b) Rest Water Level.
(c) Electric Conductivity - taken at various depths.
(d) Pumping Test Yield - taken at various depths.
(e) Recovery Rates.
(f) Geological Sections.

76. By plotting and analysing this data it is possible to build up a detailed picture of the water resources, their origin, physical and chemical characteristics and the amount of the reserves.

77. Tests to ascertain the porosity of the geological strata, the vertical and horizontal transmission rates therein, pore pressure and chemical make up must be carried out and tabulated. Electric borehole logging may be of assistance.

78. Initial theories are confirmed or may have to be modified or even discarded and new theories of origin worked out until a thorough understanding of the water is established.

79. Whilst the geophysical and geological pictures are being proved, knowledge will be accrued to enable the hydrological aspects to be more closely evaluated.

80. The suitability of water for drinking, agriculture and industrial purposes varies according to the total solids dissolved in it since its origin as rain. This may be from present depositions or from depositions which have fallen in the past.

81. Dependent upon where the rain was deposited, the strata through which it has passed and the time and condition of storage, so will its quality vary.

82. Also, the nature of the water bearing strata will determine how readily or otherwise the strata will give up its water and how quickly it will refill from re-charge sources.

83. Recent developments in the use of radio isotopes have enabled estimates to be made of the age of water in underground strata.

84. It will be seen therefore that until water is found and tested its suitability cannot be ascertained.

Phase V - Development.

85. Whilst the field work is in train it is possible to commence formulating ideas as to the development of the ground water reserves.

86. Economics will have a large bearing on whether ground water resources are developed or whether other forms of provision of water such as distillation of sea water or electro-dialysis of brackish water may be more readily and economically achieved. The solution may hinge on the availability of cheap heat or power. In some countries ground water reserves may be remote from areas of population. Consideration may therefore have to be given to transferring population to habitable areas nearer the reserves. In this case however it is essential that precautions are taken not to pollute the reserves.

87. For the development for agriculture, normally prospecting will have been directed to regions where soil qualities, drainage of cultivated areas and other factors have been considered.

88. In the case of industry it may be that the final location is decided only after the location of the reserves has been established.

89. Ground water sources may be polluted and the water abstracted therefrom may require purification before being taken into use.

90. Typical pollution may be :-

(a) Physical — Colour.
pH Value.
Temperature.

(b) Chemical — Sulphates.
Carbonates.
Chlorides.
Nitrates.
Fluorides.

(c) Biological — Bacteria.

Each of the above can prove harmful or undesirable unless removed or controlled.

91. Treatment costs will depend on the extent of purity required and the amount of pollution existing.

Phase VI - Control of Abstraction.

92. The use of ground water means the taking up of natural reserves. These if taken up without care and forward planning can be quickly destroyed by excess pollution or by cessation of the source.

93. There is danger in the uncontrolled use of water for agriculture particularly if it is artesian in nature resulting in the saturation of ground and the destruction of agricultural facilities in the region.

94. Hydrological and Meteorological Studies obtained from the survey should give a sound basis on which to base abstraction rates.

95. For long term development replenishment and abstraction should balance.

96. The study of hydrology and rainfall is an interesting but complicated subject. As stated previously all water derives from rain and during its history the losses of deposited rain near the surface can be as follows :-

(a) by evaporation on the surface due to the action of sun and wind before penetrating the surface.

(b) there can be soakage losses in the strata leading from the surface to underground reservoir.

(c) A vast amount of the water can be lost by run-off.

97. Generally light rains only contribute to evaporation and there is very little absorption. This style of precipitation not penetrating into the ground is particularly noticeable in desert areas where the baked surface of the ground is very rarely penetrated more than skin-deep by early rain. One effect of the light rains would appear to be to break up and render more permeable the hard baked surface skin. Later rains generally penetrate and the heavier the rain the greater the possibility of penetration until such time as sheet flooding occurs when it is possible that the rapid translation of water from one water shed to another may result in lack of penetration and to the loss of the water in run-off.

98. Using figures ascertained during the field work by the measurement of percolation and infiltration; and for the vertical and horizontal transmissibility of water in the geological formations, it is possible to understand more clearly the hydrological picture.

99. Recent developments have utilised electronic methods of ascertaining the proportions of dissolved radio isotopes in underground water to endeavour to establish the age of these waters. It is possible that underground water sources contain water which is accrued therein from the beginning of geological time although due to underground wasting etc., there is always an amount of turn-over in the greater number of types of underground sources.

100. Underground water is contained in the interstices of rock or sedimentary formations.

101. Obviously the denser the rock the less likely it is to hold water but some dense rocks such as granite when weathered and shattered can hold tremendous volumes of water and be extremely good reservoirs.

102. In the majority of formations there is movement of the underground water and this movement has to be studied and developed if a successful underground water supply system is to be established and be maintained.

103. It is very rarely that water is found in a complete state of rest and every endeavour must be made to ascertain the forces which are causing the movement of this water and the direction in which it is moving. By understanding and exploiting these forces it is possible to produce water which is useful to man.

104. It is possible sometimes to use the movement of water to leach out dissolved materials from the parent structure so that water quality can be improved with increased draw-off.

105. The water bearing structures are in fact rather like large sponges with the water contained in the interstices. The texture of the structure will determine the rate at which the formation will give up its water.

106. A gravel formation with little or no fine material will obviously yield water more rapidly than will a sedimentary rock with fine interstitial passages. On the other hand clays which can contain a high percentage of water are usually formed with such fine interstices that they can be persuaded only to give up a small proportion of their water.

137. As the development and abstraction programmes are being fulfilled, further records should be kept so that knowledge of the performance of the underground water source is kept under review. Modifications to these programmes may have to be made from time to time in the light of knowledge gained.

108. It has been said that the quantitative assessment of ground water resources is the conclusive stage of a water exploration programme. The Author's opinion differs from this as he considers that this is an intermediate stage only. Until abstraction and production begin it is not possible to be certain how the underground sources will perform.

109. He considers therefore that there is danger in considering the above quantitative assessment of the resources as a finality. Cases have arisen where glowing pictures have been painted of the quality and quantity of underground reserves which have proved to be false when production has been put in hand.

110. Expert knowledge and teamwork is essential for the successful prosecution of ground water exploration. Administrators can assist in the matter by ensuring that these experts are given complete freedom to pursue their search without interference by financial, political or other extraneous sources which will detract from their service to the community.

111. The accretion of knowledge concerning underground water is continuous and man's understanding of the subject is incomplete. Ground water prospecting therefore will hold its sense of adventure, independence of thought and uncertainty until all the gaps in this knowledge are filled in.

Recent Findings in Qatar.

112. Reference to one particular item of ground water prospecting may be of interest to the Conference.

113. The hydro-geological work and drilling carried out on behalf of the Government of Qatar in 1952 may be of interest.

114 The work was phased and organised in the manner shown earlier in this paper and a very high degree of co-operation and teamwork was achieved.

115 Qatar is an arid peninsular in the Arabian Gulf whose average rainfall is of the order of 2½ inches per year. Deposition is spasmodic and may vary between ½ in/yr and 6 in/yr locally. Topographic study showed a pattern of shallow depressions scattered over the area under review. Geological studies showed that these depressions had been formed by wind erosion. Except at the coastal fringe the majority of the depressions catch depositions and store a proportion of the water underground.

116 Water conveyed rapidly to the depressions seeps through the depression floors and is stored in lenses of potable quality water of considerable depth.

117 Water soaking into the general catchment area outside the depressions percolates downwards and is stored in a mound of lower quality water the top surface of which in general follows the main contours of the country.

118 This survey proved that the sweet water lenses are contained in the mound water which is itself balanced on saltwater under the peninsular.

119 This type of hydrology is unique in the area of the Arabian Gulf and is completely different from that occurring in the nearby countries of Saudi Arabia, Bahrain, Kuwait, Southern Iran, Iraq, Jordan or the Trucial States.

120 A deep probe into lower horizons to attempt to tap into beds outcropping in the hinterland of Saudi Arabia proved artesian water but of a quality completely unsuitable for domestic or agricultural use.

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